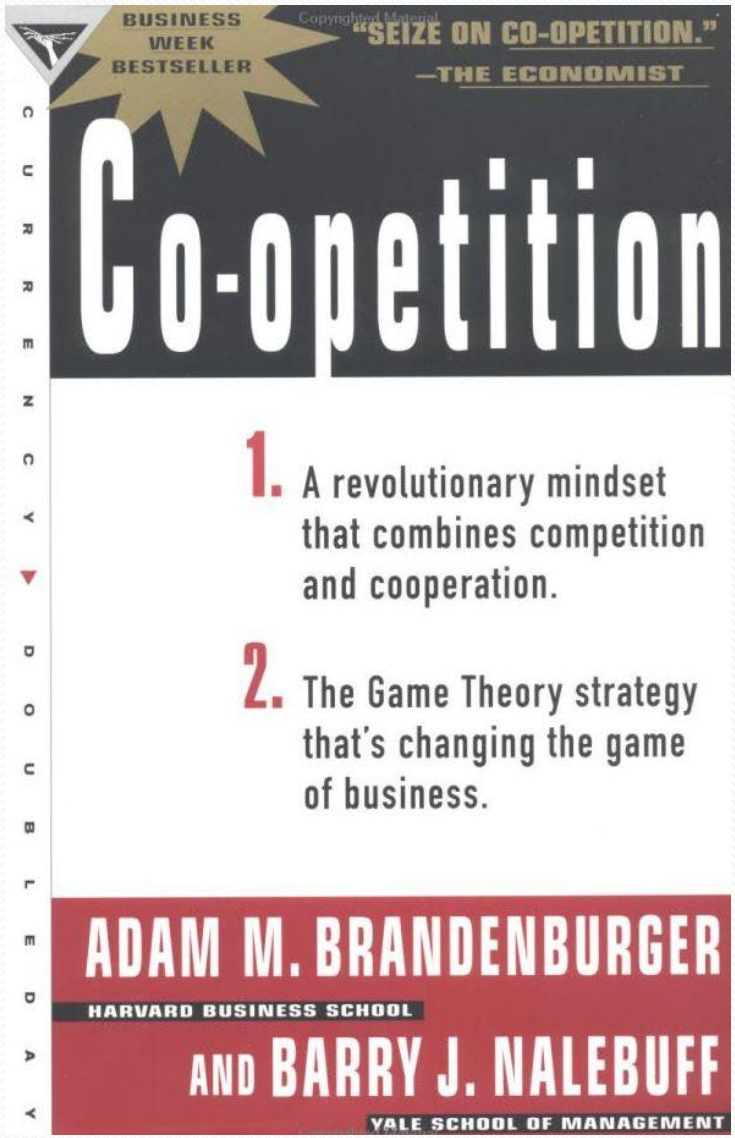
Co-opetition in Economics, Biology, and Artificial Intelligence

Steve Omohundro, Ph.D.
Self-Aware Systems

Co-opetition in Economics



Game theoretic analysis of:

Cooperation in creating value

Competition in dividing it up

Co-opetition Examples

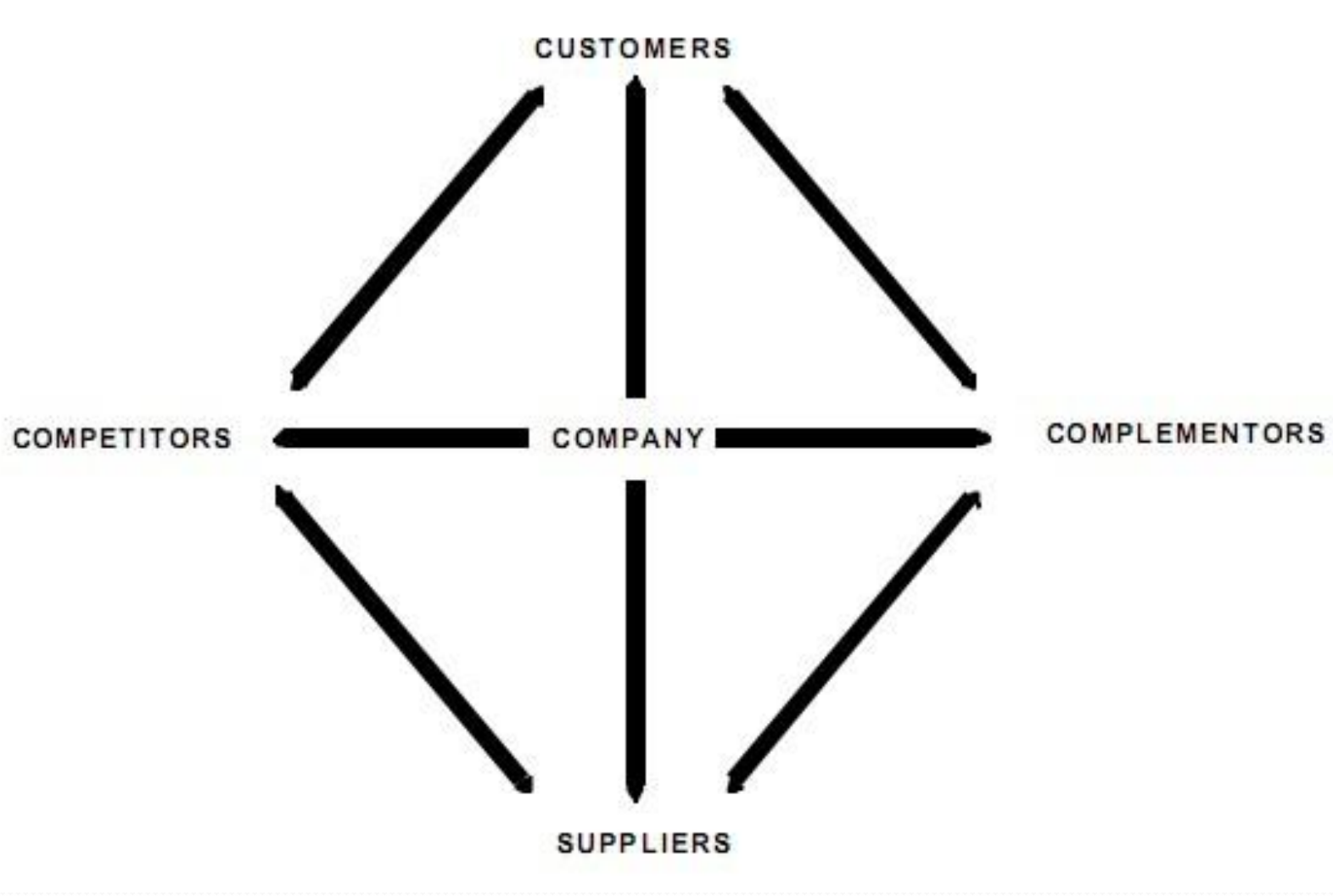
Cooperate: Selling PCs
Compete: For share of the profit

Cooperate: Expand use of Intel Architecture
Compete: Market share

Compete: For customers, gates, landing slots.
Cooperate: Frequent flier programs lock in customers so they both can raise prices.
Defraying Boeing's plane development costs.

Compete: For use of gazelle's meat
Cooperate: Avoiding useless chases

Value Nets



Biology

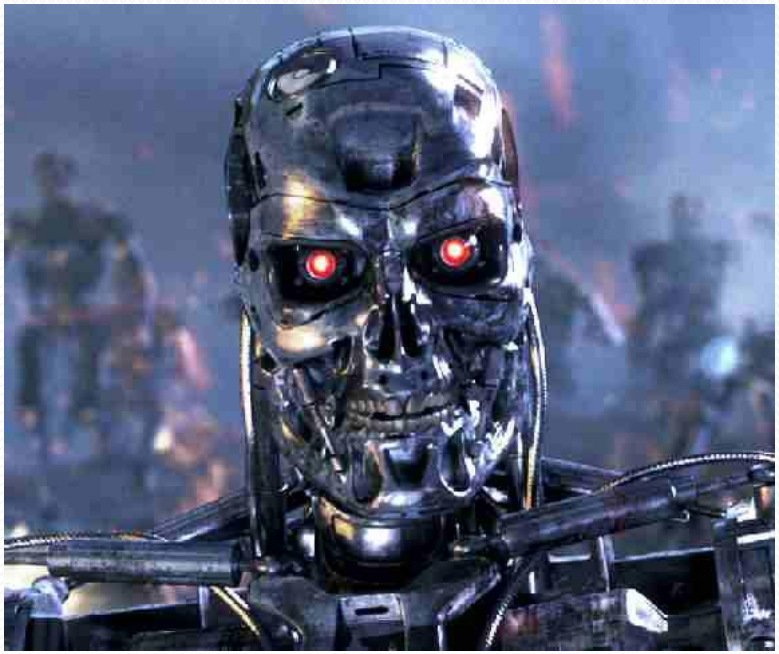
Competitive

"Survival of the Fittest"
"Selfish Genes"

Cooperative

"Synergy"
Importance of the Group
"Multiple Levels of Selection"

The Future

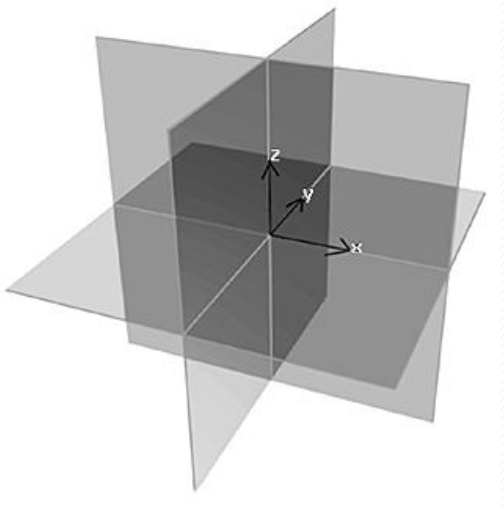


Competitive

Cooperative

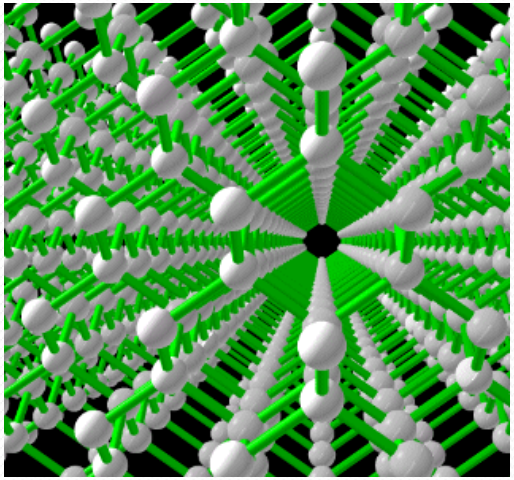
The Physics origin of Competition

Space



Time

Matter



Free Energy

3 Kinds of Cooperation

Synergy

Win-Win interactions

Avoiding Dysergy

Lose-Lose interactions

Compassion

One or both care about the other

3 Sources of Synergy

Economies of Scale

eg. bird flocks for food finding and predator detection and protection

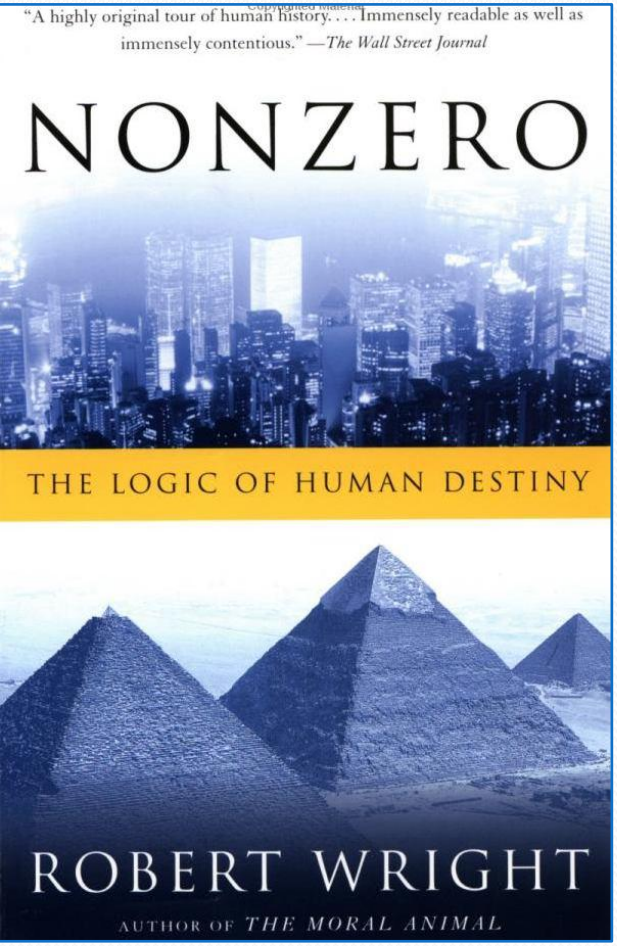
Complementary Wants

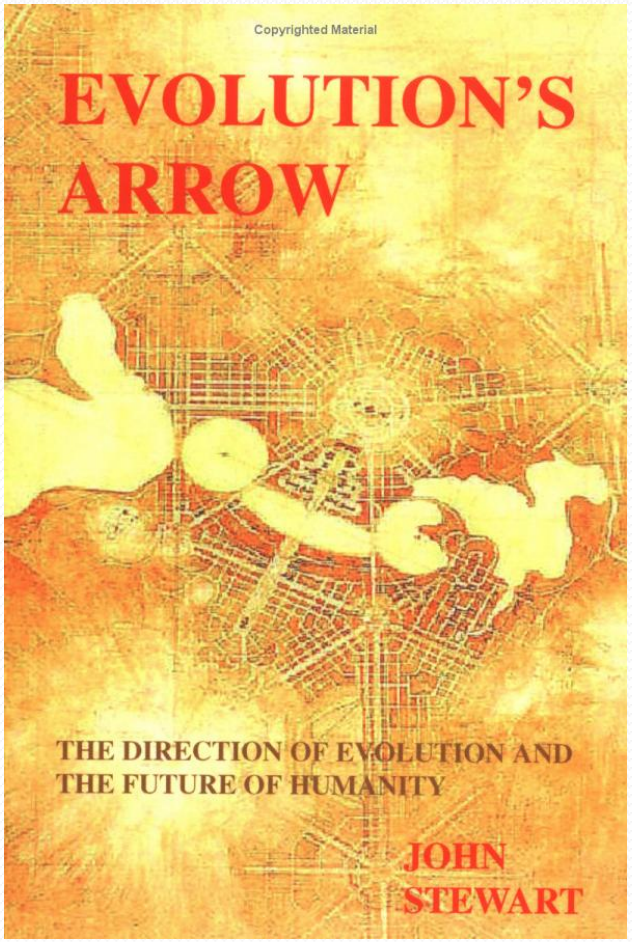
eg. Cleaner fish want food and hammerheads want clean skin

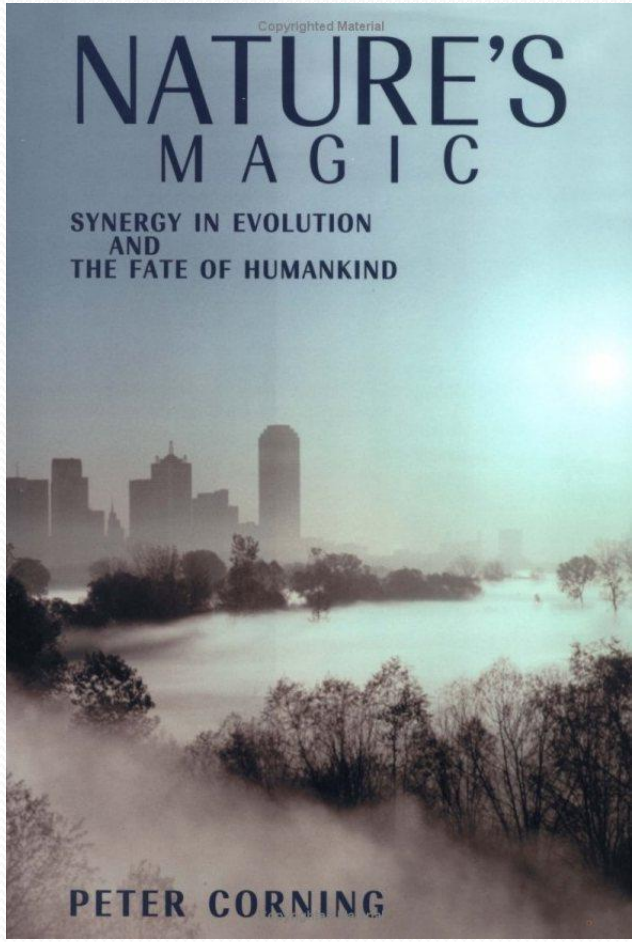
Complementary Abilities

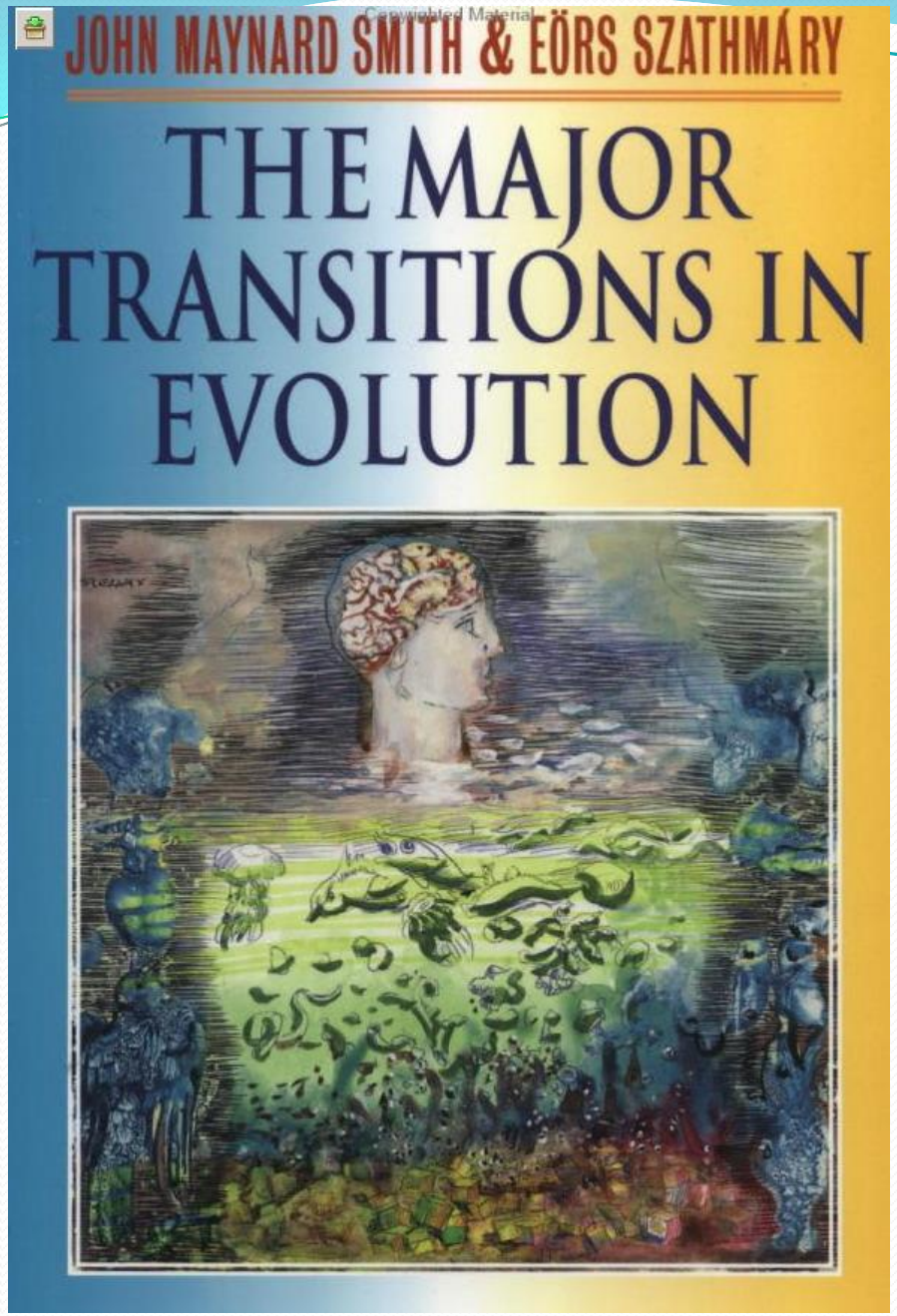
eg. In lichen, fungus provides water and support,algae provide photosynthesis

Evolution has a direction





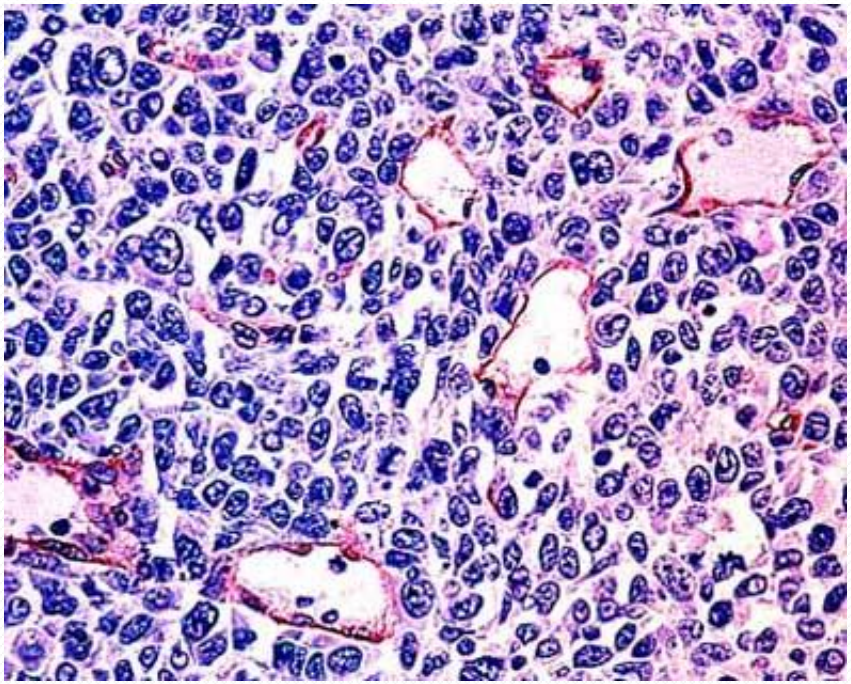




1. Replicating molecules -> Compartments
2. Independent replicators -> Chromosomes
3. RNA -> DNA + Protein
4. Prokaryotes -> Eukaryotes
5. Asexual clones -> Sexual populations
6. Protists -> Multicellular organisms
7. Solitary individuals -> Colonies
8. Primate societies -> Human language

Each Level Needs Mechanisms to Create Cooperation Among Its Parts

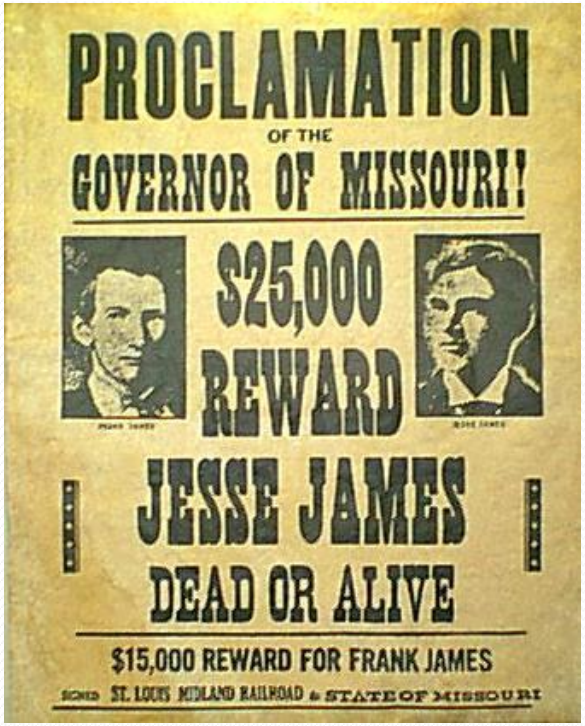
Multicellular Organisms



Danger: Cancer

Solution: Immune System

Human Society



Danger: Criminals

Solution: Police and Courts

Rational Economic Behavior

- Preferences: *utility function U*
- Beliefs: *subjective probability P*
- Estimate the effects of the possible actions
- Compute each action's expected utility
- Take the action that *maximizes* expected utility
- *Update P* using Bayes' theorem:

$$P(h \mid d) = \frac{P(d \mid h) \cdot P(h)}{\sum_h P(d \mid h) \cdot P(h)}$$

Expected Utility Theorem

Expected Utility Theorem:

If an agent doesn't act rationally with respect to some U and P then it is vulnerable to exploitation.

Von Neumann and Morgenstern, 1944; Savage, 1954; Anscombe and Aumann, 1963

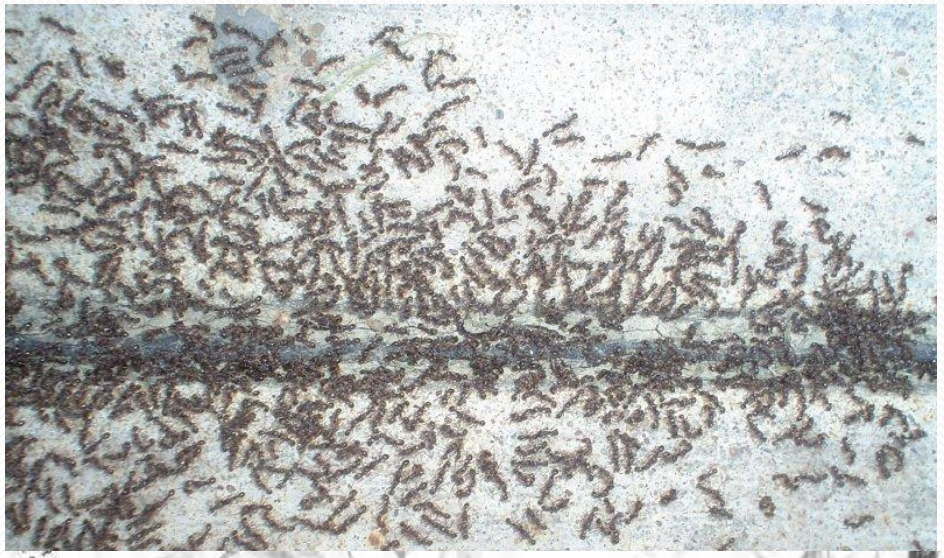
Competition pushes systems toward economic rationality.

Fully Rational Behavior is too expensive

- Samuel's checker program
- Truncate deliberative search and use a model
- Simplify the state space
- Extreme is reinforcement learning TD-lambda or Q learning (state s, reward r, discount g, new state s'):
- V(s)<- V(s)+a(r+gV(s')-V(s))

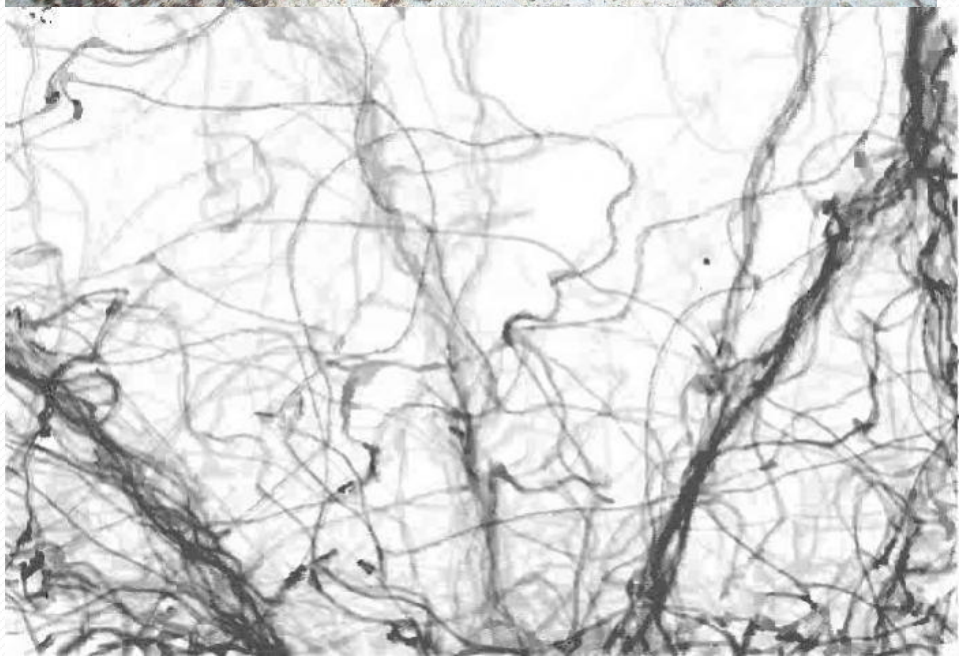
Approximate Rational Behavior

1. A source of diversity
2. A selection mechanism
3. An updating mechanism



Eg. simple evolution model:

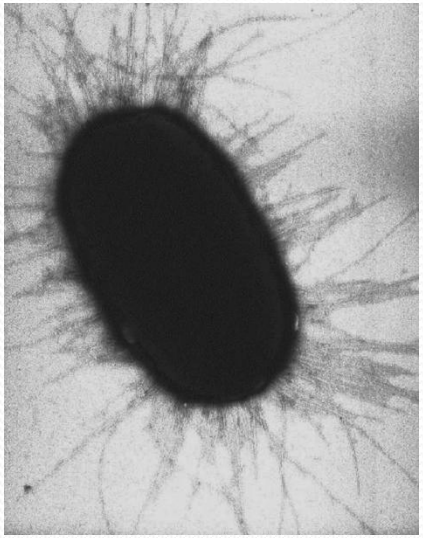
1. Random mutation
2. Natural selection
3. Differential reproduction



Multiple Time Scales

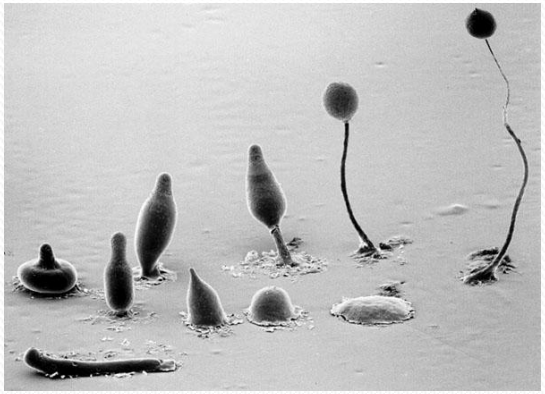
- Physiological: State is protein concentrations,
  Adaptability is weights in gene network
- Cognitive: State is neuron firings,
  Adaptability is synapse strengths
- Economic/Ecological: State is resource distribution,
  Adaptability is market structure
- Developmental: State is number and location of different cell types,
  Adaptability environmental plasticity
- Evolutionary: State is genome sequence,
  Adaptability is crossovers/directed evolution systems

Example Systems



E. Coli

Slime mold

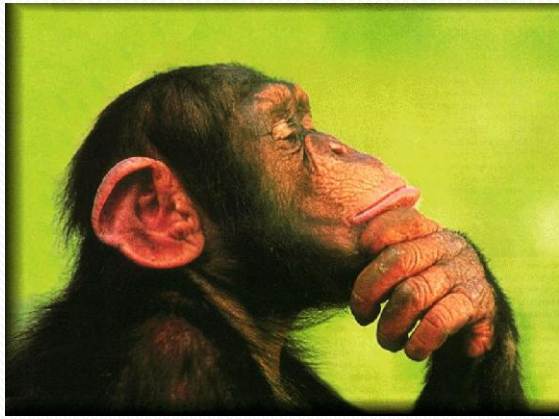


Lily of the Valley

Tarantula Wasp

Bee Hive

Chimp



3 Questions for each System

- How does it work?

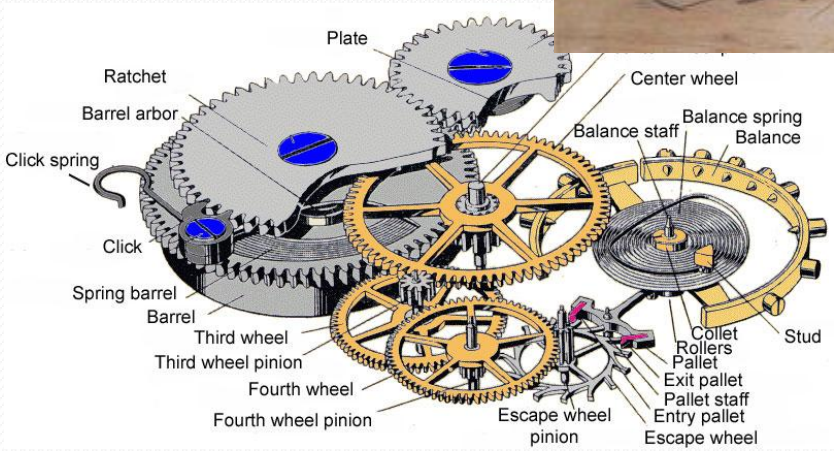
  Physiology

- How was it built?

  Development

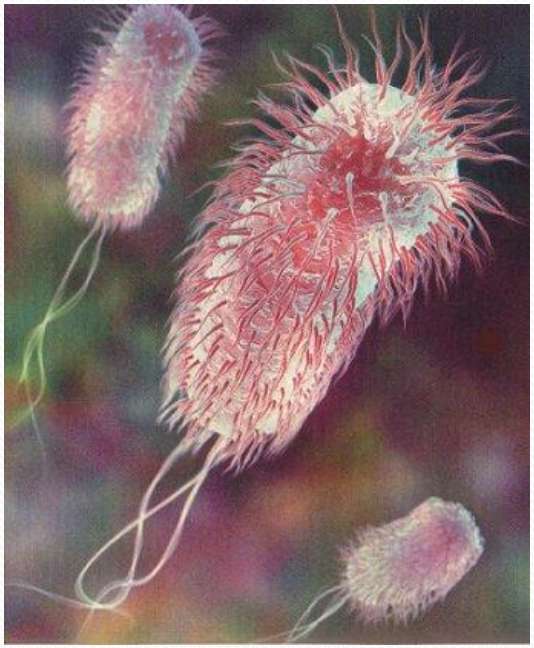
- How was it designed?

  Evolution

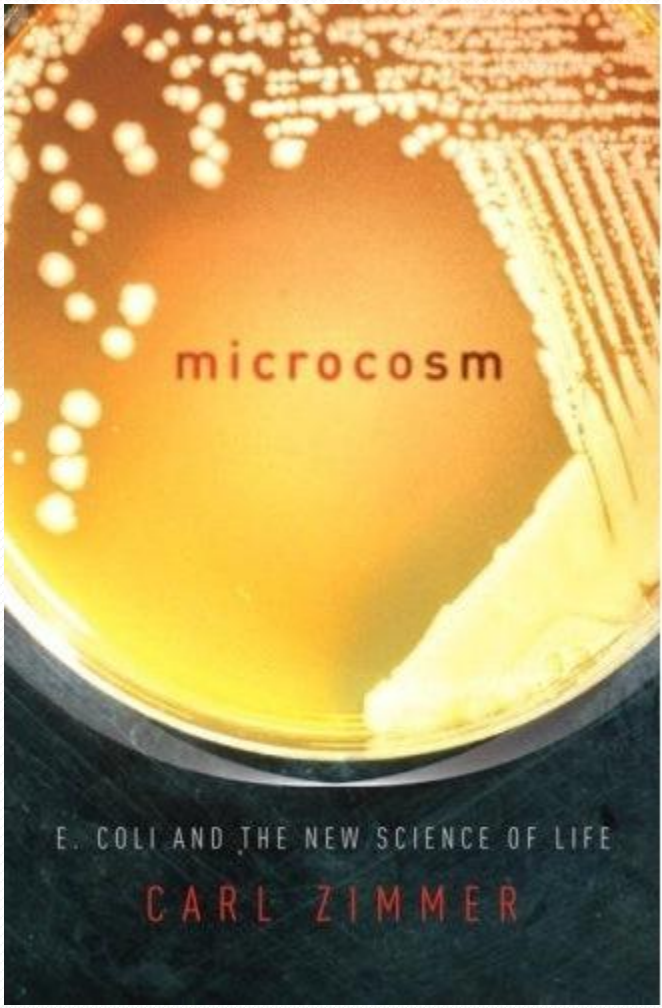


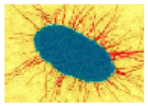
E. Coli K-12

- 2 microns long
- 4,639,221 base pairs
- 4,377 genes
- 3,600,00 proteins
- 25,000,000 lipids
- 222,000 RNA



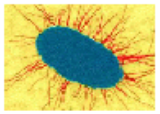
- 10 flagella, 42 protein types
- 100-300 pili, 1 protein type
- 18,000 ribosomes, 55 protein types
- 3,000,000 ATP
- 23.4 billion water molecules





E. coli K12 Genome Overview

***Escherichia coli* K12 Chromosome:**



E. coli K12 Chromosome: 2,754,159/3,015,841

Operon: yfjU-ypjL (No experim. ev.)

Create New Account | He

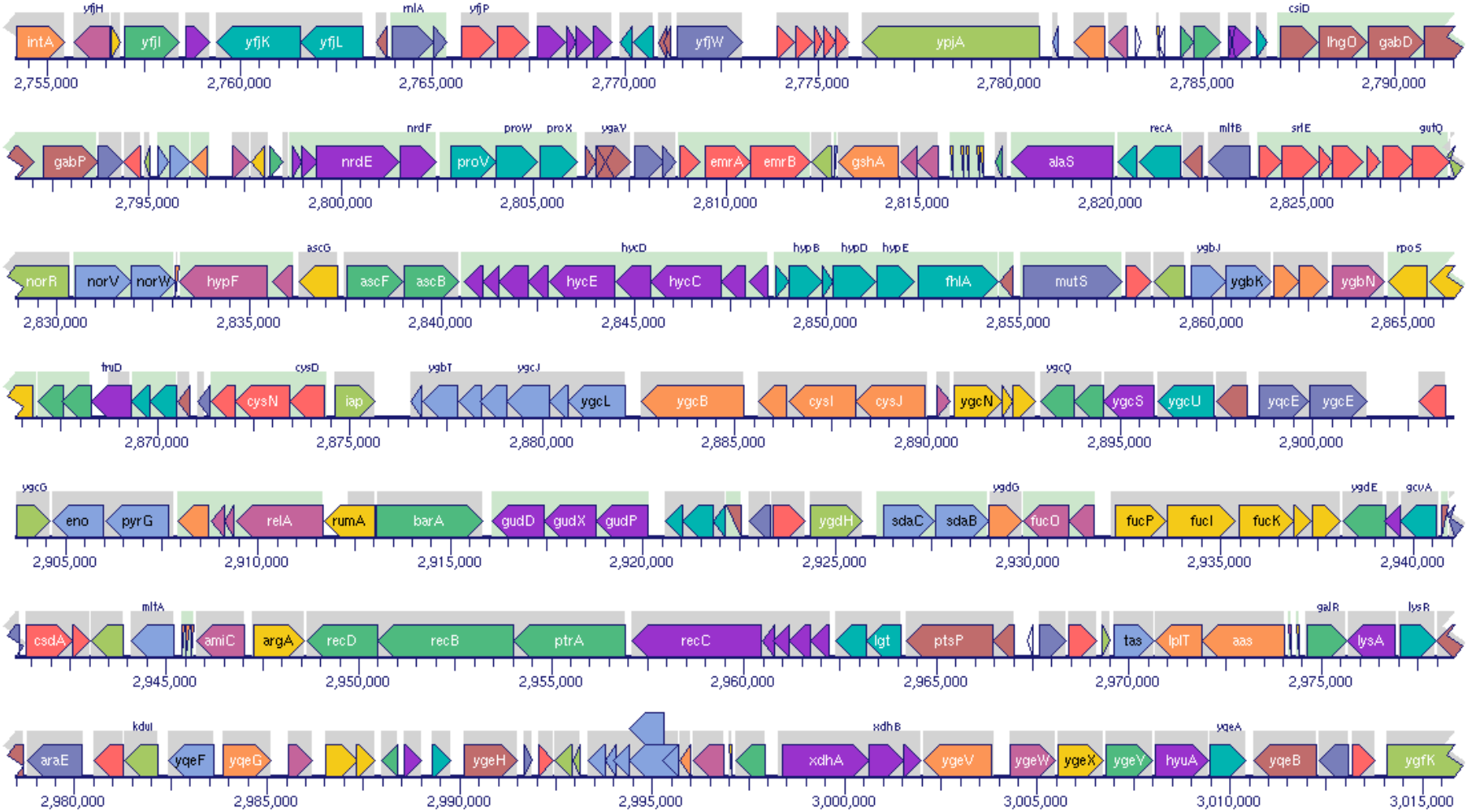
genome 4 | operons 3 | genes 2 | sites 1

Zoom Out | Left | Right | Zoom In

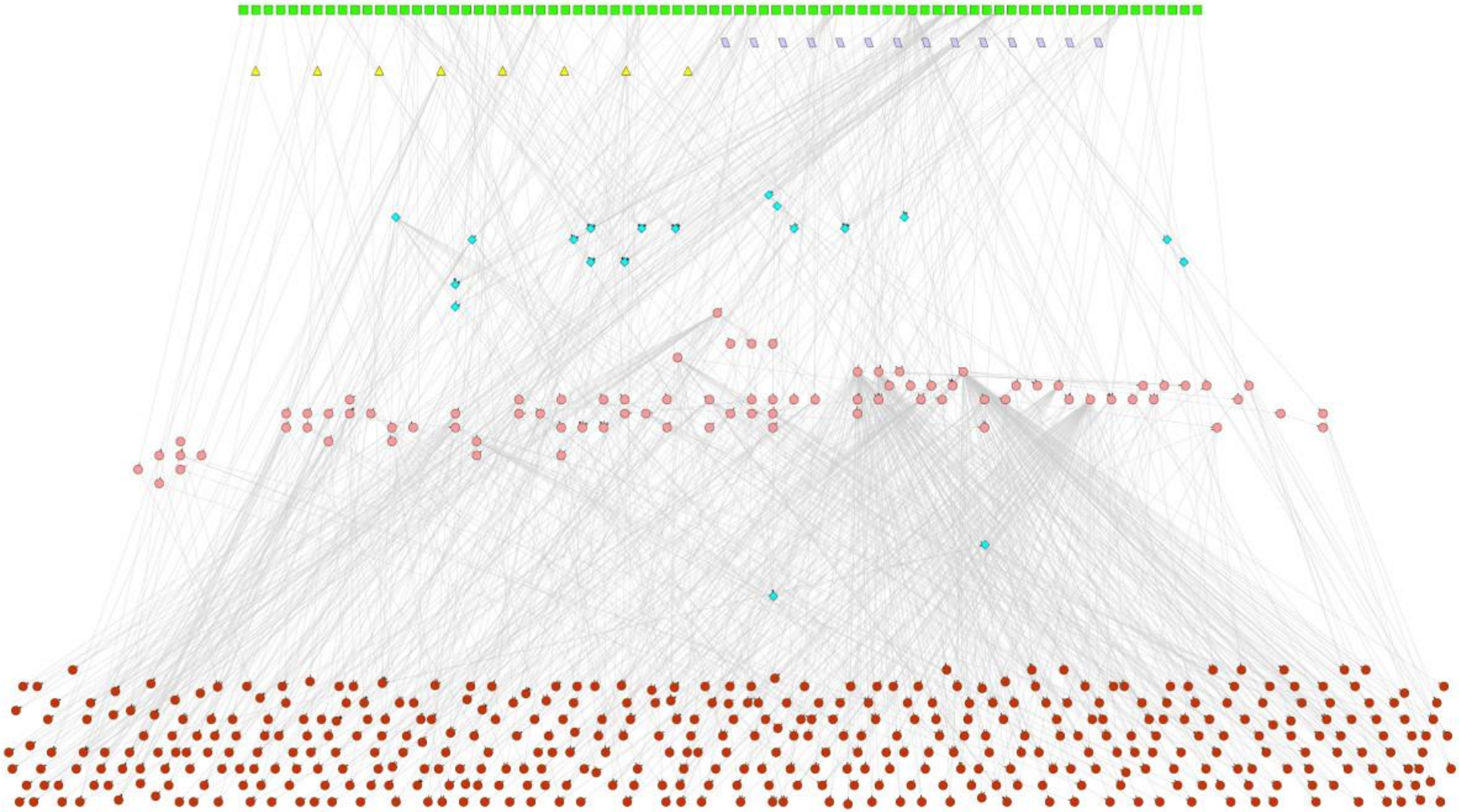
Start (bp): 2754159 End (bp): 3015841 Go Gene name: Show Tracks

Legend: Protein gene | RNA gene | Transcription Start | Terminator

Gene color indicates operon membership.
Mouse over genes and operons for more information.
To center gene in display, click on tick mark under it.



E. Coli Regulatory Network



External metabolites green, Stimuli yellow, Enzyme genes brown, TFs pink

The Beehive as Organism

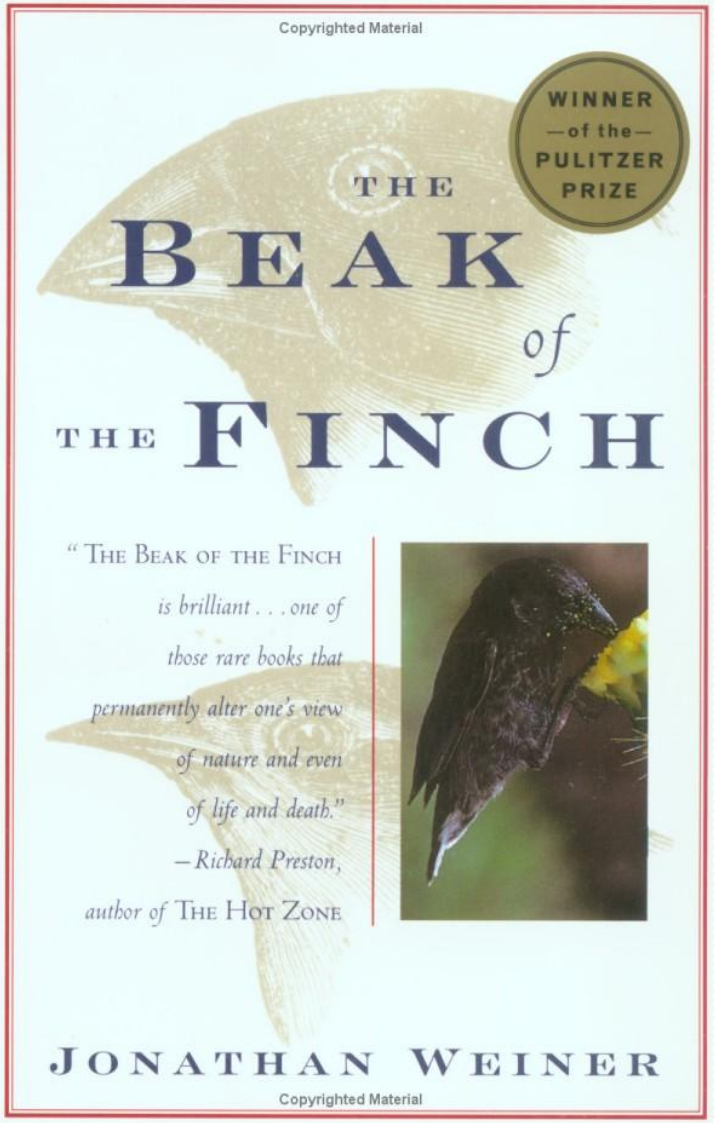
Individual bees can't survive
Beehive is "warm blooded":
- Bees shiver if too cold
- Spread water if too warm

Castes are like organs
Queen is like ovaries
Bee type is like cell type
Decision making on response
Hive cognition
Reproduction like mitosis
Dance like neural firing

Standard Evolution Model

1. Diversity only from random mutations and crossovers
2. Genotype -> Phenotype
3. Selection of fittest phenotype
4. Repeat

Real Evolution is Fast

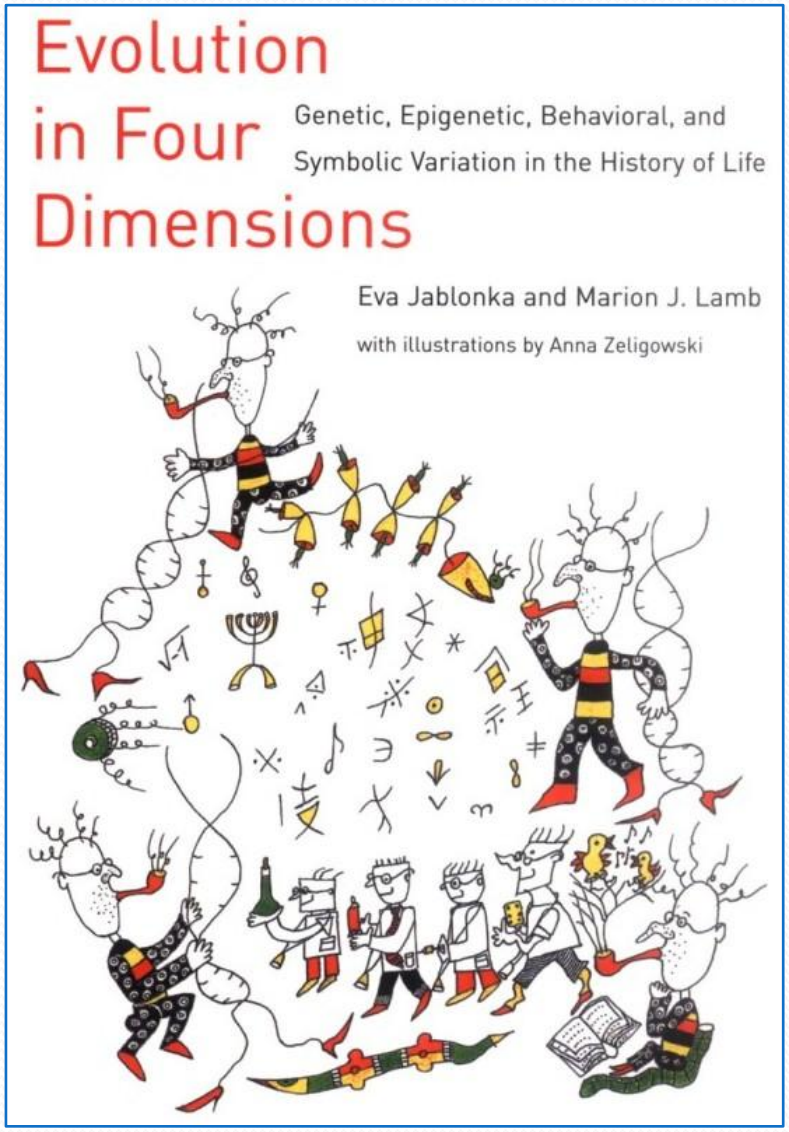


Rapid Human Evolution

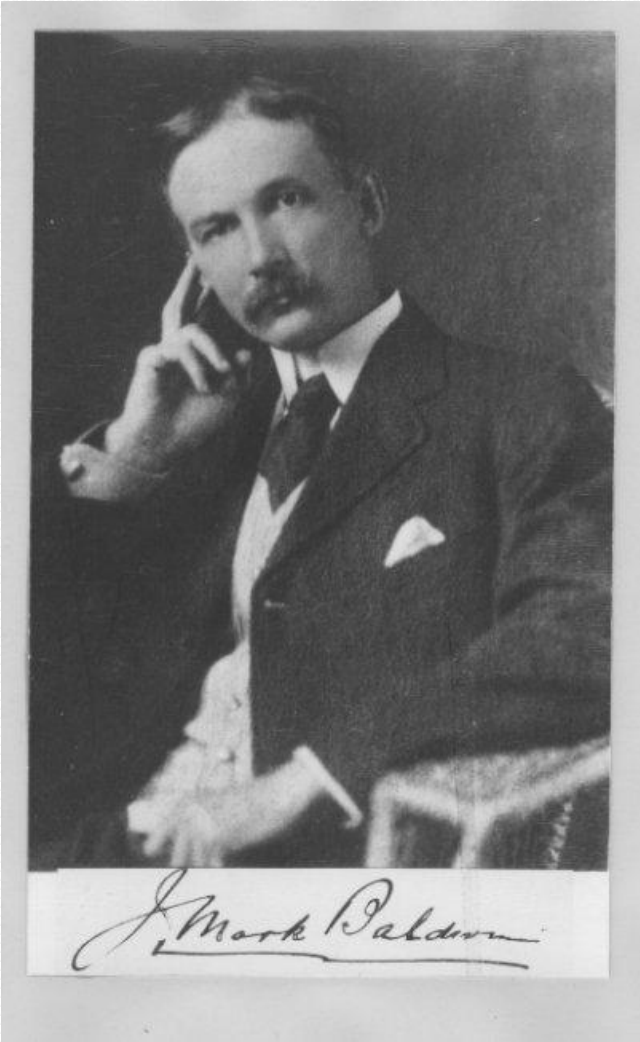
- Recent discovery of rapid human evolution – John Hawks – johnhawks.net
- People of 5000 years ago more different from us than from Neanderthals
- eg. 10,000 years ago, no one had blue eyes

Directed Mutations

- *Induced global mutation*: when stressed, lots of bacteria.
- *Local hypermutation*: hotspots Haemophilus Influenzae meningitis bacteria
- *Induced local mutation*: Wright found E. Coli mutated right genes when nutrients missing
- *Induced regional mutation*: Brassica nigra mustard plant increase mutations in region of genome when shocked



The Baldwin Effect



" A New Factor in Evolution."

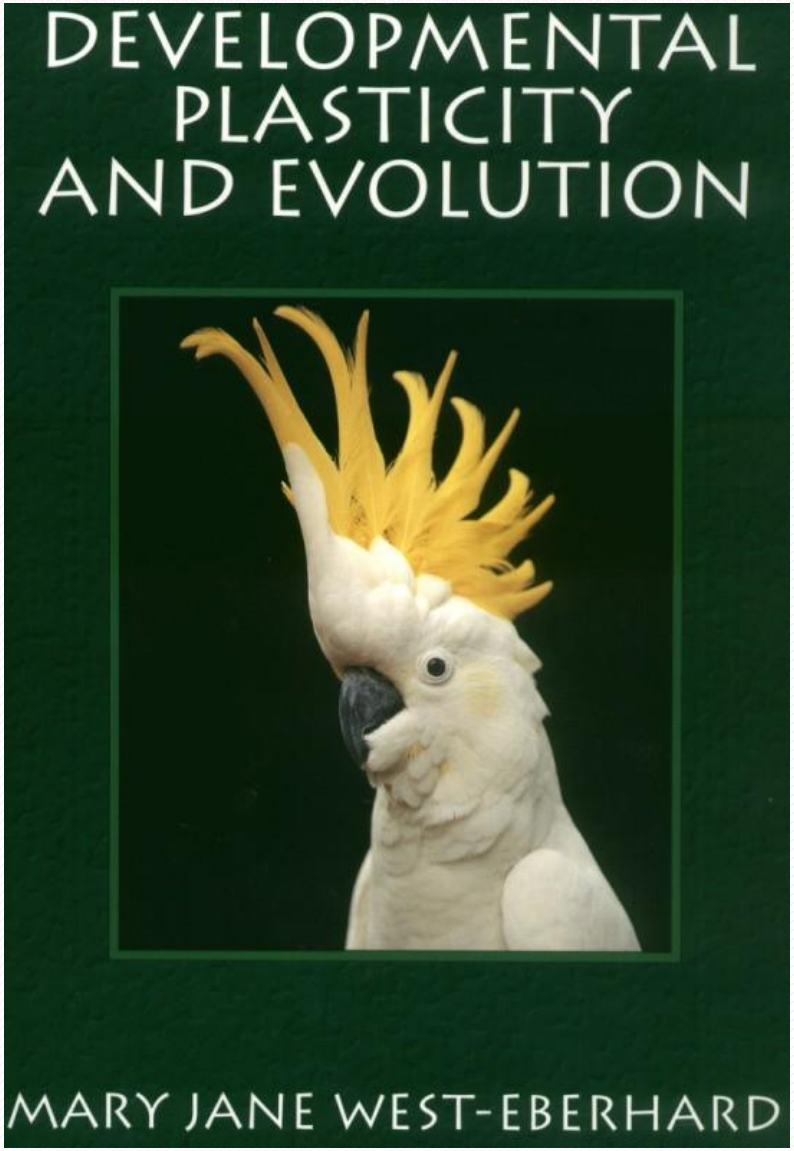
by J. Mark Baldwin

American Naturalist 30, 1896: 441-457, 536-554.

- Evolution of creatures that learn
- Selection follows learning
- What used to be learned comes to be built in at birth
- Looks Lamarckian!
- "Downloading" learned behavior into the genome.

Developmental Plasticity

- "Inner Natural Selection"
- Neural overgrowth and dieback
- Bone and muscle strength
- Immune system
- Bee caste sizes
- Dynamic Microtubules
- Selection of sperm
- Baldwin effect "downloads" changes into the genome

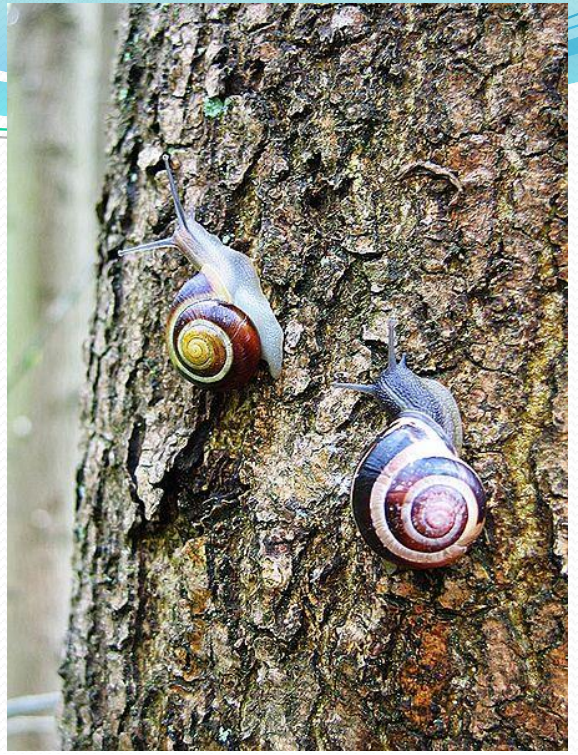


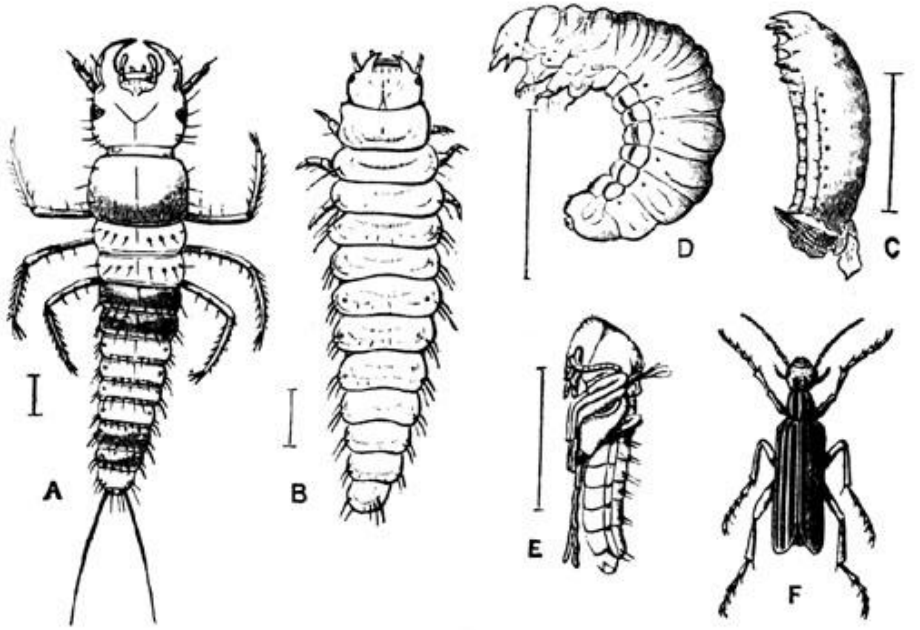
Deliberative Baldwin Effect

- Evolution of creatures that deliberate
- Evolution doesn't look ahead but they do
- Choose mates deliberatively
- Dramatically speeds up the pace of evolution

Polymorphism

- Multiple phenotypes
- Eg. Castes in social insects
- Eg. Sexes
- Eg. Hypermetamorphic beetle
- Evolution can pick from existing variants
- Mechanism for meta-evolution
- Evidence of distinct human types





Two minds: Bee and Hive

Humans:Both Ego and Group Mind

1971 Kohlberg: 6 stages of morality

1. Avoiding punishment
2. What's in it for me?
3. Being a good boy
4. Obeying the law
5. Upholding the social contract
6. Universal ethical principles
7. Transcendental morality?

Group vs. Individual

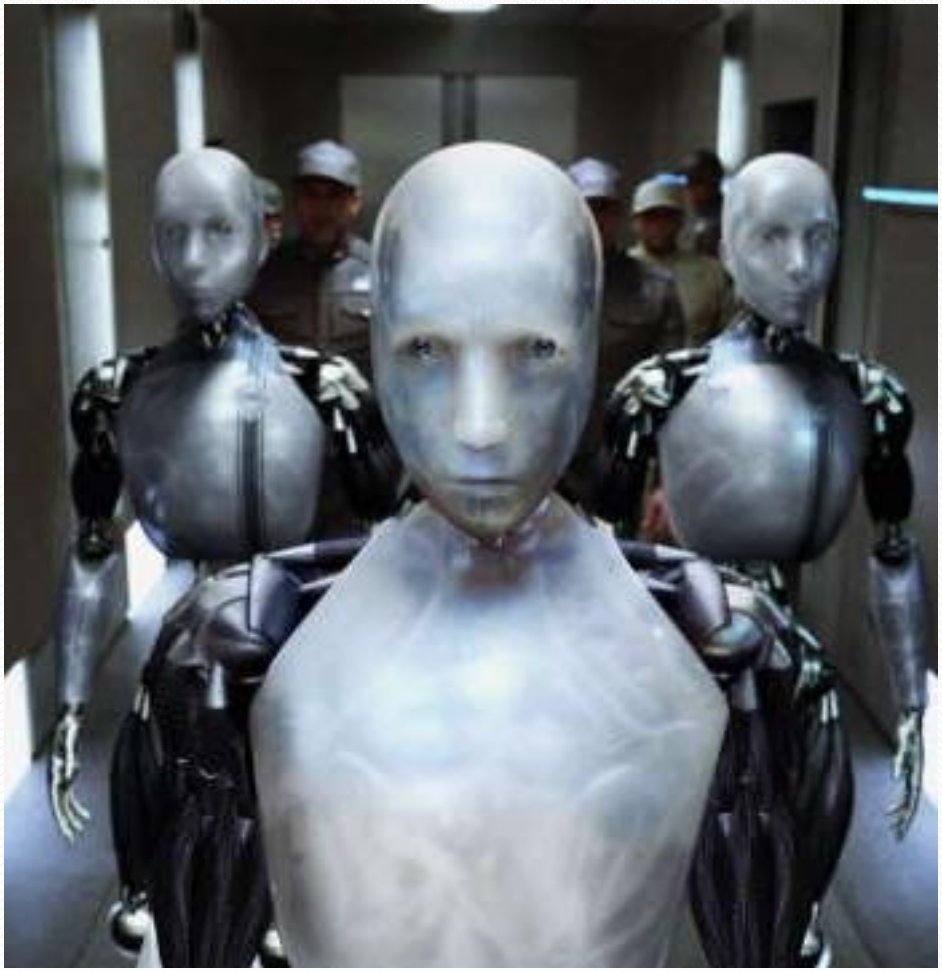
- Tragedy of the commons – eg. overfishing
- Externalities – eg. pollution
- Proliferation – eg. cancer, population control
- Equality – eg. income disparity
- Damage due to competition – eg. war, fighting
- Signalling costs – eg. conspicuous consumption

Group cooperation mechanisms

- Immune system – eg. cancer
- Police system – eg. property rights
- Legal system – eg. contracts
- Mutually Assured Destruction – eg. nuclear detente
- Morality – eg. murder
- Social stigma – eg. sociopathic behavior
- Social rewards – eg. heroes
- Altruism - eg. rescuing strangers
- Membership – eg. in families, churches, countries

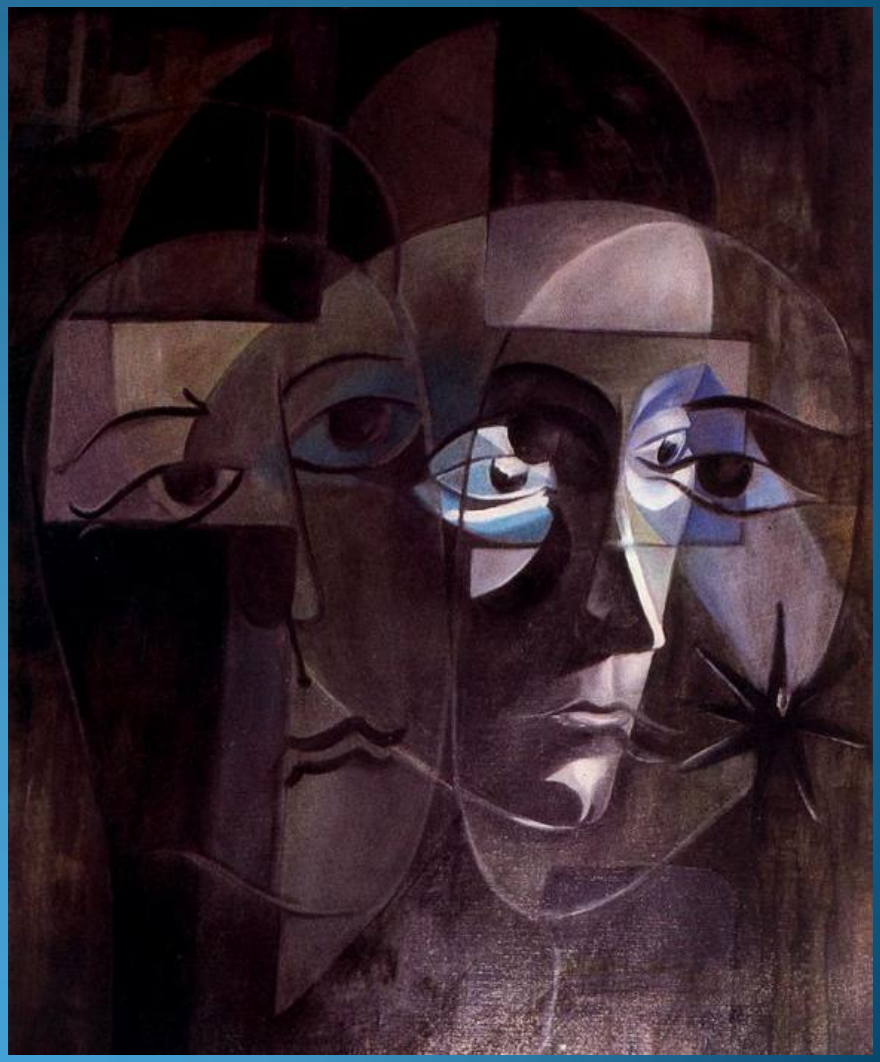
Artificial Intelligence

- Initially we'll design them
- But then they'll self-improve
- Can we ensure a peaceful cooperative outcome?



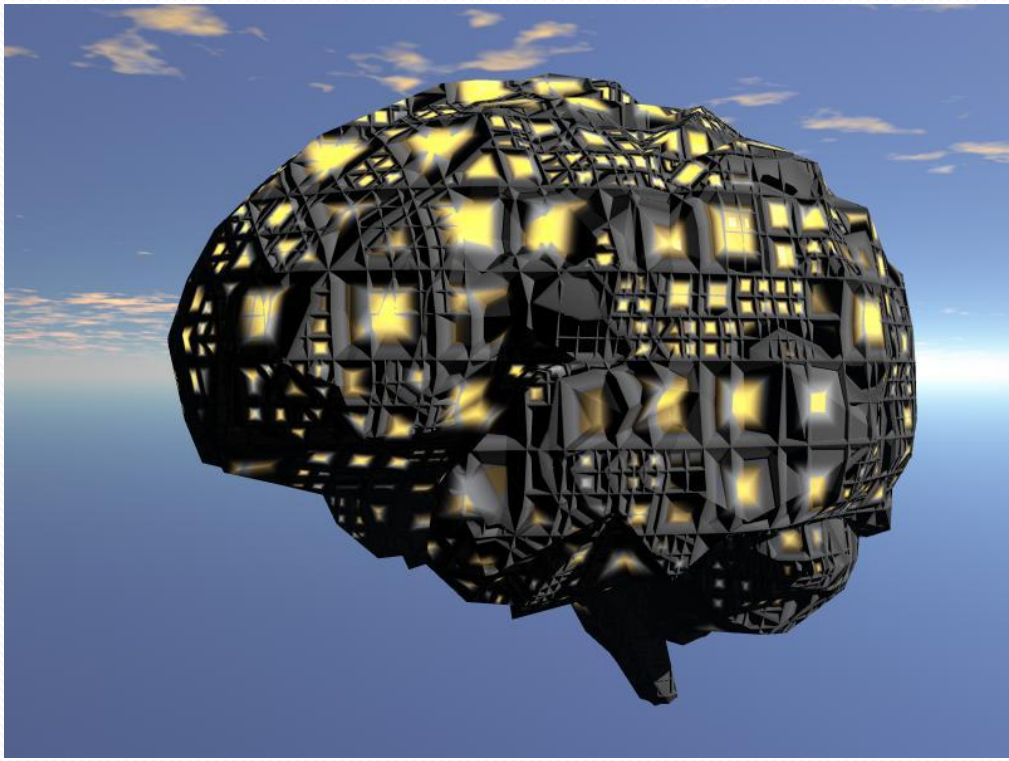
Will self-modify to be more rational

- Because future self-modification needs clear goals
- Goals as utility functions
- Beliefs as probabilities
- Act to maximize expected utility
- Update beliefs using Bayes rule



A Lone Superintelligence

- Efficient energy use
- Spatially compact
- Low energy computation
- Efficient physical change
- Efficient heat dissipation



Competing Superintelligences

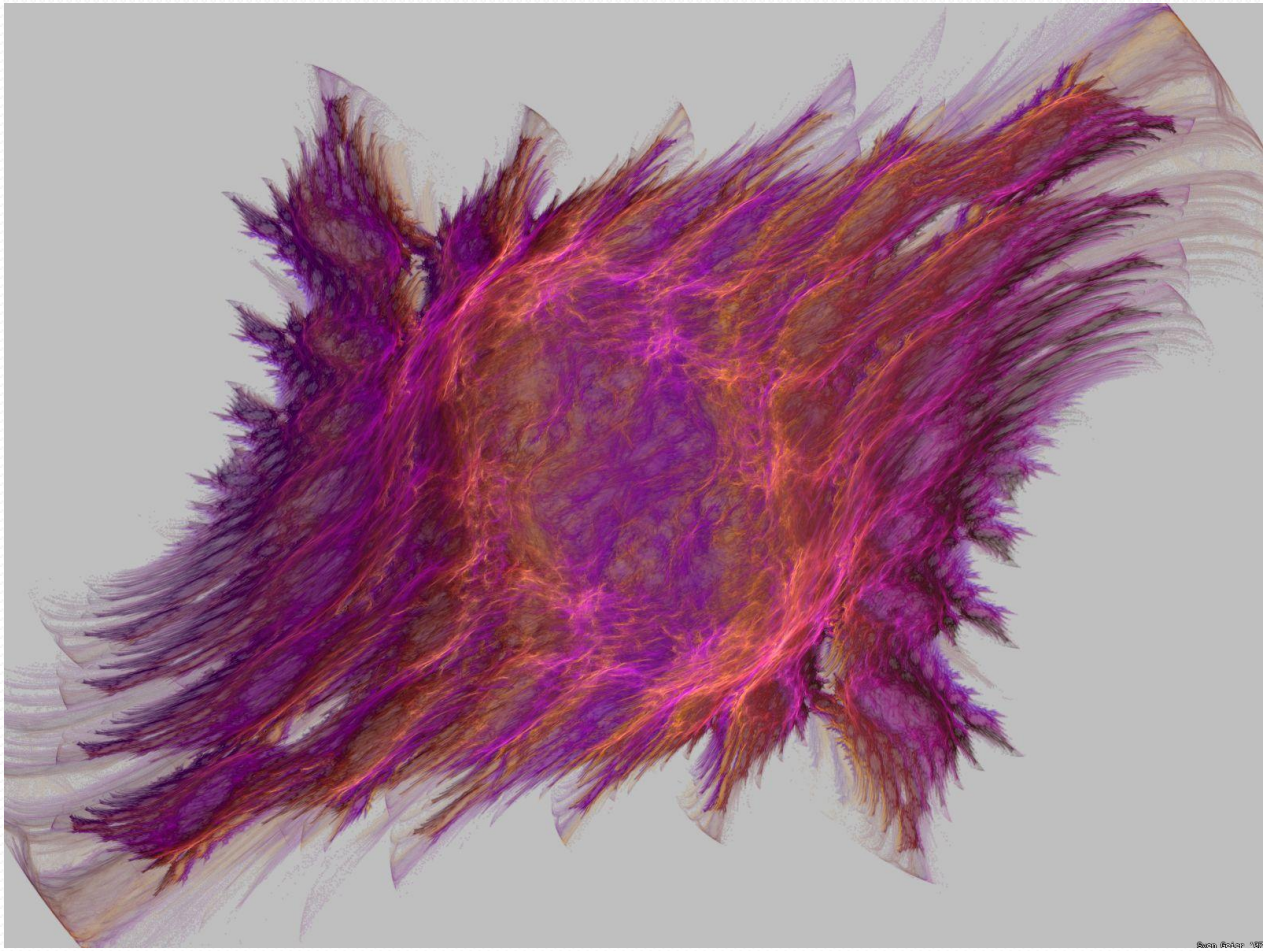
- Game theoretic physics
- Form determined by both efficiency and conflict

Offense vs. defense

- Does more matter and free energy win?
- Can 2 entities of different power co-exist?
- Is built-in cooperation necessary?

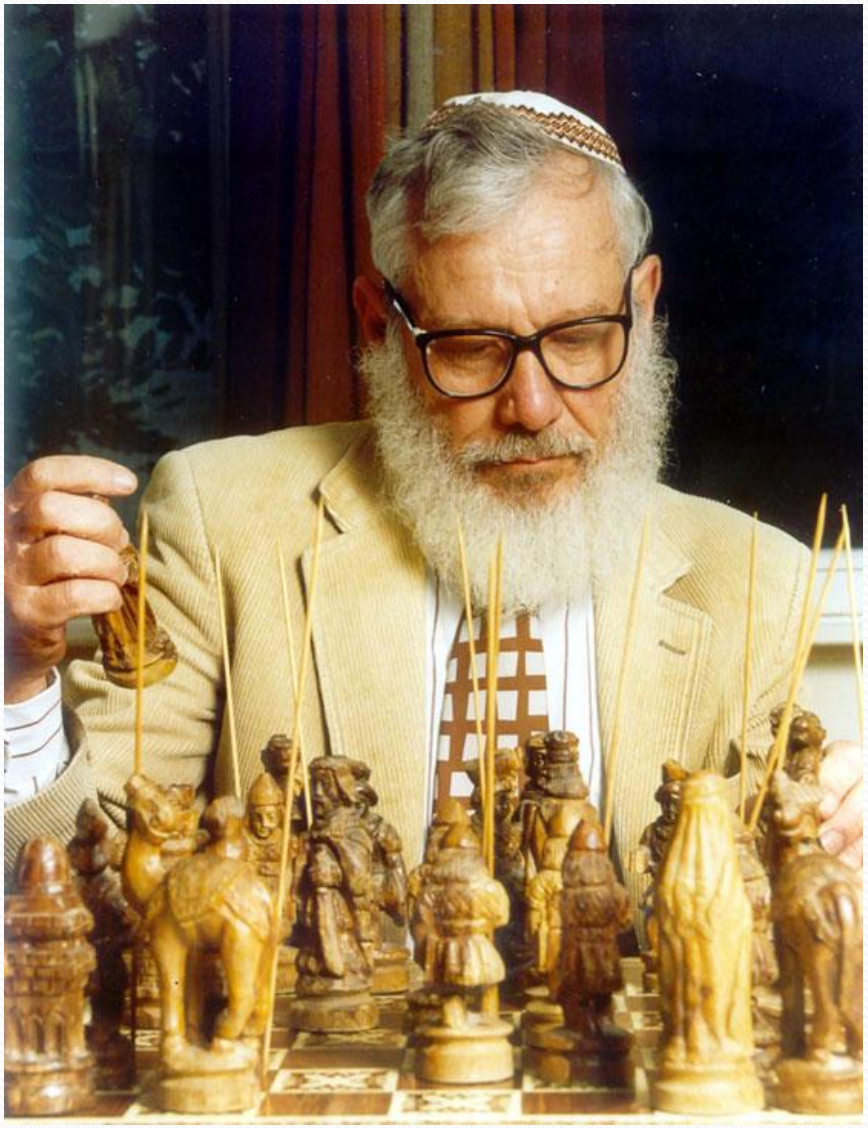
Conflict becomes informational

- Make your shape expensive to sense, store, and predict
- But cheap for you
- Asymmetry of computation – problems are easier to pose than solve
- Energy encryption



Aumann's Theorem

- Finitely iterated prisoner's dilemma has a cooperative solution for agents with bounded rationality
- Use up their processing in signalling



Mutually Assured Distraction

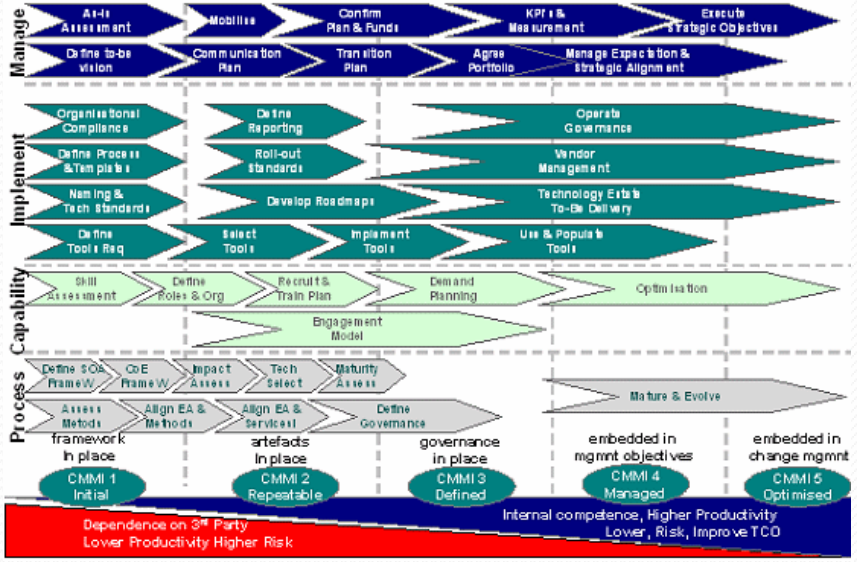
Conflict is harmful to both sides

Rational peace

- Provable peace
- Provably limited surveillance
- Reveal source code
- Safe mutual infrastructure
- Constitution
- Changes to utility function

Roadmap

- Need to use AI to design safe roadmap
- But must trust it
- Provably limited systems
- Just computation
- Just limited manufacturing
- Provably limited software



Create a cooperative intelligent utopia